ARIZONA DEPARTMENT OF TRANSPORTATION

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REVIEW OF RETROREFLECTIVE SIGN SHEETING MATERIALS, PRACTICES AND POLICIES

Special Report

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16. Abstract

ADOT is interested in establishing minimum retroreflectivity requirements for sign sheeting used on the State Highway System. This study consisted in a thorough literature review of minimum retroreflectivity needs and a nationwide survey which identified types of sheeting used and usage policies among the states.

The distance at which a sign can be detected and recognized must be greater than the visibility distance required by the driver to make a decision and initiate and complete a maneuver, if necessary. Since at night visibility is heightened primarily by retroreflection, there must be a minimum retroreflectivity requirement that assures the visibility distance required by the driver.

Forty-eight states were surveyed regarding sign sheeting and 35 states answered the questionnaire. The responses showed that most states have a policy that establishes the type of sheeting used for each sign class. However, minimum reflectivity requirements (SIA) are used only for purchase of new signs and new sign sheeting. The most recent study on minimum retroreflectivity requirements (SIA) was performed by Olson at the University of Michigan. He conducted a field study of sign conspicuity and recommended minimum retroreflectivity requirements for several types of signs depending on the complexity of the surroundings and travel speed. Additionally, FHWA is sponsoring a project that will determine minimum visibility requirements and the level of retroreflectivity required to satisfy those requirements.

The values determined by Olson appear to be high, especially for high complexity areas, but study is the best currently available and Olson's SIA values were used in this study to estimate the minimum grade of sheeting necessary for each sign type. Considering the economic impact of using more retroreflective sheeting, it appears reasonable to wait for the results of the research sponsored by FHWA before recommending a retroreflective sheeting policy for ADOT.

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Traffic Signs, Sign Sheeting, Minimum Retroreflectivity Requirements.

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METRIC (SI*) CONVERSION FACTORS

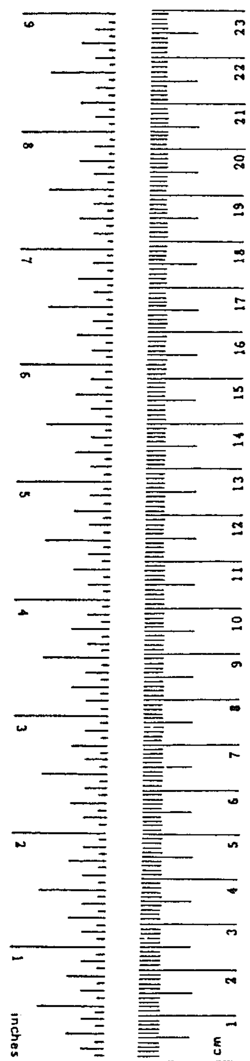
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

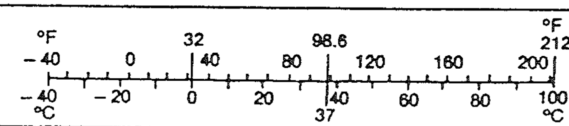
Symbol	When You Know	Multiply By	To Find	Symbol
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

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I - INTRODUCTION

Traffic signs have to be seen and legible at night as well as day. The Manual of Uniform Traffic Control Devices (MUTCD) establishes that all signs "... shall be reflectorized or illuminated to show the same shape and color both at day and night" (1). Nighttime visibility is generally achieved using retroreflective sheeting materials.

To assure adequate guidance for night drivers, the Arizona Department of Transportation (ADOT) is interested in establishing minimum retroreflectivity requirements for sign sheeting used on the State Highway System. The following report is the result of the first stage of this sign sheeting research. This report consists of a thorough literature review of minimum retroreflectivity needs and a survey identifying types of sheeting used and current usage policies in other states.

I.1- REFLECTIVITY

Reflection of light is the process in which a ray of light that strikes a surface is bounced off. There are three types of reflection: mirror, diffuse and retroreflection (2). Retroreflection occurs when the light that strikes a surface is redirected back to its source. Traffic signs must be retroreflective, since the light must be reflected back to the driver.

There are four sign-related factors that affect a driver's visibility (2):

1. Brightness, or the amount of light reflected from the sign that reaches driver's eye,
2. Contrast: internal (background-copy) and external (sign-environment),
3. Conspicuity, or the probability that a sign located in the visual periphery will be seen at a given distance, and
4. Legibility.

All these factors are influenced by the retroreflective characteristics of the sign sheeting material used.

I.2 - DEFINITIONS

Luminance or retroreflectance of a point retroreflector can be quantified using the Coefficient of Luminous Intensity. The Coefficient of Luminous Intensity for a small (point) retroreflector is defined as the ratio between the luminous intensity of the reflector in the direction of observation, and the illumination of the reflector on a plane perpendicular to the light. It is expressed as candelas (cd) per lux (lx) in the International System of Units (SI). If the retroreflector is not a point source, as is usually the case, the brightness can be computed per unit area and the Coefficient of Retroreflection (R') is used. R' is expressed in SI as candelas per lux per square meter. The English equivalencies for these units are candelas per foot-candle per square foot and the coefficient is described as Specific Intensity per Unit Area (SIA). The conversion factor, from SI to English units is one. The reflectance SIA value is the same as the cd/lux/m^2 value.

The retroreflectance of a retroreflector is not a property of the material itself, but depends mainly on two angles (as shown in Figure 1):

1. The entrance angle (ϕ), formed between the incoming light ray and the normal to the surface, and
2. The observation angle (θ), between the incoming light beam and the reflected light beam as it is seen by the motorist.

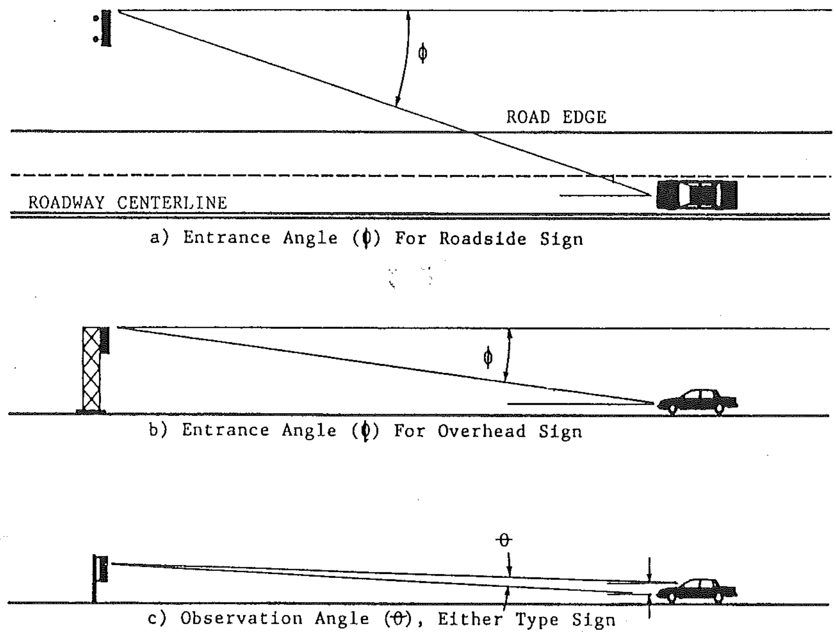

Figure 1. Entrance and Observation Angles (2).

The entrance angle depends on sign location and orientation, and vehicle distance to the sign. The observation angle depends on the distance between the sign and the vehicle and the height of the driver's eye with respect to the vehicle head lamps.

I.3 - TYPES OF RETROREFLECTIVE SHEETING

Retroreflectivity of sign sheeting materials is achieved through one of the following principles (2):

1. Spherical Retroreflection. Retroreflection is achieved through a combination of glass spheres or beads and a reflective surface located at the focal point. An incoming ray of light is directed by the sphere to its focal point, which is behind the sphere. At the focal point, a reflecting surface (mirror type) reflects the ray, which, after being bent again at the surface of the sphere, returns to its source.
2. Prismatic (or cube-corner) Retroreflection. The incoming ray of light, after being reflected several times at the reflecting surfaces of the prism, is redirected back to the source.

Both principles are used to design retroreflective sheeting material. There are three basic types of retroreflective materials:

1. Enclosed glass beads or lens,
2. Encapsulated glass beads, and
3. Prismatic.

In the enclosed beads material, small glass beads are imbedded in a layer of transparent, colored plastic. The reflecting surface consists of a metallic shield placed behind the plastic. The encapsulated material consists of glass beads placed on top of a metallic reflection shield, protected by a transparent plastic sheet that is supported slightly above the beads, without touching them, to create a tiny air chamber that improves retroreflectivity. Prismatic material consists of countless small cube corners inserted in a transparent plastic film. These three types are shown in Figure 1.

Based in the retroreflection principle used and the brightness (SIA) achieved, the major sign sheeting types or grades are:

1. Engineering Grade (EG) enclosed glass beads,
2. Super Engineering Grade (SE) enclosed glass beads,
3. High Intensity (HI) encapsulated glass beads,
4. High Intensity prismatic,
5. Diamond Grade (D) ultra-high intensity prismatic sheeting, and
6. Microprismatic high-intensity vinyl sheeting.

SE sheeting has approximately double retroreflectivity (SIA) and HI sheeting has between three and four times more retroreflectivity than EG sheeting. SE differs from EG sheeting in the quality of the encapsulated glass beads

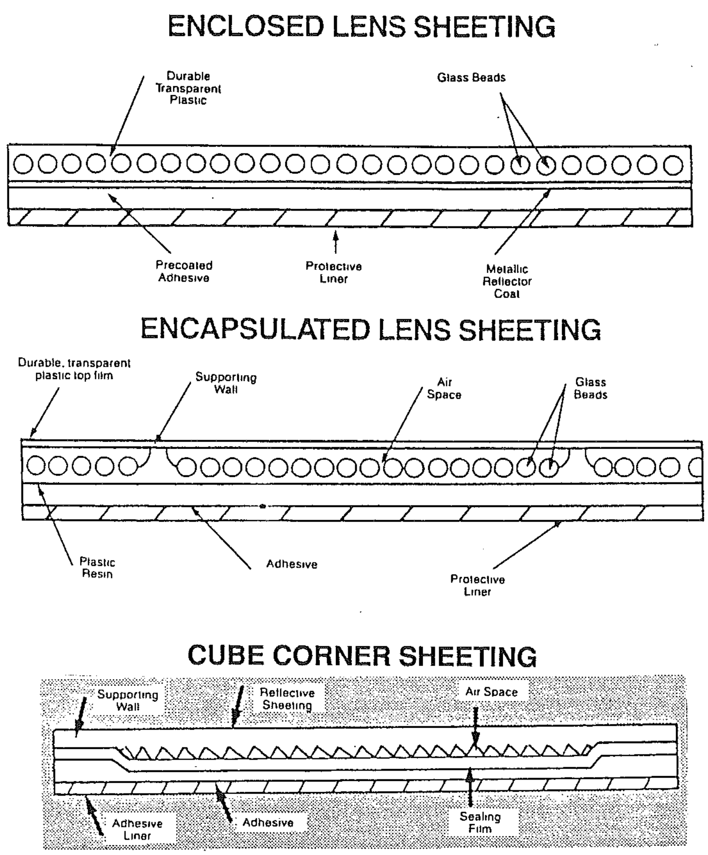

Figure 2. Types of Retroreflective Sheeting Material.

II - RETROREFLECTIVITY STANDARDS

II.1 - DIFFERENT RETROREFLECTIVITY STANDARDS

There are three main national standard classifications for traffic sign sheeting materials:

1. Standard Specification for Construction of Roads and Bridges on Federal Highway Projects, FP-85, section 718 (3).
2. AASHTO Standard Specification for Retroreflective Sheeting for Traffic Control, M 268-84 (1990) (4).
3. ASTM Standard Specification for Retroreflective Sheeting for Traffic Control, D 4956 -90 (5).

1. **FP-85** recognizes three types of sign sheeting materials (3):

- Type II, composed by enclosed-lens sheeting, includes two classes:

  - Type II, commonly known as "Engineering Grade" sheeting, and
  - Type II-A, known as "Super Engineering Grade" .

- Type III, commonly known as "High Performance" sheeting, has three classes:

  - Type III-A,including encapsulated-lens sheeting,
  - Type III-B, prismatic type sheeting, and
  - Type III-C, also prismatic type (authorized by a memorandum dated November 3, 1989, by the Federal Land Highway Program Administration).

- Type IV, a high performance vinyl sheeting of low durability, is typically used for temporary traffic control devices (such as orange cones).

2. **AASHTO** considers four types of sign sheeting materials (4):

- Type I: low reflectivity sheeting (utility grade) not recommended for highway signs,
- Type II: medium reflectivity sheeting (engineering grade),
- Type III: high intensity reflective sheeting , and
- Type IV: high intensity reflective vinyl sheeting.

3. Finally, **ASTM** uses six types of sign sheeting materials (5):

- Type I: medium-intensity retroreflectivity sheeting referred to as "engineering" grade.
- Type II: medium-intensity retroreflectivity sheeting referred to as "super engineering" grade.
- Type III: high-intensity retroreflective sheeting, typically encapsulated glass-bead.
- Type IV: high-intensity retroreflective sheeting, typically unmetallized microprismatic retroreflective material.
- Type V: high-intensity retroreflective sheeting, typically metallized microprismatic retroreflective material (used for delineators).
- Type VI: elastomeric high-intensity retroreflective sheeting, typically microprismatic.

ASTM types I, II, III and IV are used for highway signing devices and delineators, type V for delineators and type VI for roll-up signs, etc.

Table 1 shows how each grade of sheeting material is classified by the three national standards.

TABLE 1. STANDARD RETROREFLECTIVE SHEETING MATERIALS.

Sheeting Grade	FP-85 Type	AASHTO type	ASTM type
Engineering	II	II	I
Super Engineering	II-A	---	II
HI Encap. Lenses	III-A	III-A	III
HI Prismatic	III-B & III-C	III-B	IV
Diamond Grade	--- (1)	--- (1)	--- (1)
HI Vinyl	IV	IV	VI

(1) Largely exceeds specifications for prismatic HI sheeting.

Black et al. provides a list of known manufacturers that produce sheeting material that meets the requirements for each grade, as shown in Table 2 (6).

TABLE 2. SHEETING MANUFACTURERS.

FP-85 TYPE	MANUFACTURERS
II	Avery\Fasson Seibulite 3M Company Kiwalite American Decal
II-A	Seibulite Kiwalite
III-A	3M Company
III-B	None (1)
III-C	Stimsonite

(1) 3M manufactures a super high intensity sheeting (Diamond Grade) that largely exceeds these specifications. Also, some states include products in this category in their approved list of suppliers. For example:
- South Carolina includes 3M (Scotchlite), Amerace Corp. (Stimsonite) and Reflexite Corp. (Reflexite),
- Texas includes Seibulite, and
- Ohio includes Reflexite.

Standard specifications only differ in a few specific retroreflective values for determined entrance and observation angles.

It is interesting to note that AASHTO does not provide standard specifications for super engineering retroreflective sheeting.

II.2 - EQUIPMENT TO MEASURE RETROREFLECTIVITY

Several different pieces of equipment are used to measure retroreflectivity. They can be grouped into three classes:

1. Laboratory Reflectometers,
2. Portable Reflectometers, and
3. Mobile Traffic Sign Evaluator

All use the same principle. A light source directs a beam of light at the sign with a predetermined entrance angle and the reflected light at a determined observation angle is measured by a photoreceptor. The coefficient of retroreflection (SIA) is computed as (7):

$$SIA = \frac{E'(D')^2 / E_n}{A}$$

Where: E' = Illuminance at the observation position,
D' = Distance between the center of the photoreceptor entrance aperture and the reference center,
E_n = Normal Illumunance of the reflector = I/D^2
I = Luminous Intensity
D = Illumination Distance, and
A = Area of the Sample.

Laboratory retroreflectometers are normally used only for material quality control and research. Portable retroreflectometers can be used for field measurements of an in-service sign's retroreflectivity. However, due to the large number of signs and the time required to evaluate each sign, these retroreflectometers are not suitable for routine evaluation of sign retroreflectivity.

To evaluate the in-service reflectance of traffic signs, a practical tool is necessary to quickly, accurately and safely measure the retroreflectance of a large number of traffic signs. The Mobile Traffic Sign Evaluator (MTSE), developed by EKTRON Applied Imaging Inc., under a National Cooperative Highway Research Program (NCHRP) contract, allows the condition of a large number of signs to be measured in a short time. The MTSE, which is a prototype, consist of (8, 9):

1. An electronic flash, which provides sufficient light to overcome ambient sign luminance,
2. A laser range finder to obtain the distance to the sign,
3. A wide-angle video camera to locate the sign,
4. A telephoto video camera to acquire a large number of sign samples, and
5. A computer with image analysis software to evaluate the video image for average legend and background retroreflectance.

To use the MTSE, the operator locates the sign using the wide-angle camera and activates the range finder when the vehicle is within approximately 10 seconds of the sign. When the vehicle approaches the required distance from the sign (200 ft. for highways and 100 ft. for local streets), the flash is activated and the telephoto camera records the reflected sign image. The information is captured and processed to obtain the retroreflectances of the background and legend (9).

MTSE equipment is still in the prototype phase, requiring field calibration and possible final adjustments. After these investigations have been completed, the vehicle will be available to state and local authorities for their evaluation.

The most prevalent method for inspecting sign retroreflectivity at the present is the human-observer method. Although, it is subjective and dependent on the experience of the inspector, this method is considered adequate for many state departments (10). The inspection can be performed at night using vehicle lights, or during the day by illuminating the sign with a 200,000 candlepower spotlight (Q-Beam) from a moving vehicle.

III -SIGN SHEETING MATERIALS SURVEY

III.1 - DESCRIPTION

A survey questionnaire to identify types of sheeting material used and current usage policies was sent to 48 states. Seventy-three percent (35 states) responded to the questionnaire. The survey's objectives were to identify:

1. Types of sheeting material used,
2. Retroreflectivity requirements for the materials,
3. The types of sheeting used for each sign class,
4. Equipment used to measure retroreflectivity,
5. The major reflective sheeting manufacturers,
6. Sign maintenance practices, and
7. Sign inspection Procedures.

Appendix I contains the survey responses.

III.2 - ANALYSIS OF THE TRAFFIC SIGN SHEETING MATERIALS SURVEY

Results presented in the following analysis were computed based on the 36 responses received (35 states plus Arizona).

1 - Sign Classification System

Most states (75%) answered that they have a system to classify the roadway signs. However, the number of classes, as well as the classes themselves vary widely, as shown in Table 3. Most classification schemes include the main classes defined in the MUTCD.

TABLE 3. NUMBER OF SIGN CLASSES.

Number of Classes	Number of States	Percentage
3-4	14 (12 use MUTCD or close)	39
5-7	9 (6 include MUTCD)	25
More than 7	4 (3 include MUTCD)	11
No response	9	25

2 - Sheeting Grades

All responding states used High Intensity Grade reflective sheeting material (HI) and most (86%) used both Engineer Grade (EG) and HI reflective sheeting material. Nine states reported they use Super Engineering Grade (SE) material, some of them on an experimental basis.

Table 4 summarizes the number of states that use each grade or type of sign sheeting material.

TABLE 4. TYPES OF SHEETING USED.

Sheeting Grade	Number of States	Percentage
High Intensity	36	100
Engineering	31	86
Super Engineering	9	25
Diamond	3	8
Reflexite	1	3

3 - Materials Used for Each Sign Category

Most respondents (89%) indicated that they have an established policy for the type of sheeting material used for each sign class. Even the states that did not have a sign sheeting policy, reported some kind of usage criteria. No state had established minimum retroreflectivity requirements based on driver's visibility needs. The types of sheeting used for each of the major sign classes are shown in Table 5 and summarized in Table 6.

TABLE 6. TYPES OF SHEETING USED FOR DIFFERENT SIGN CLASS.

Sheet. Type	Reg.Red	Reg.Other	Warning	Guide	Constr.	Overhead	Interstate
EG	8	17	12	12	2		
SE	1	--	--	2			
HI	22	14	19	12	9	6	8
EG - HI	2	2	4	6	3		
EG - SE	--	1	--	--			
SE - HI	1	1	--	--			
SE - HI - D	1	--	--			1	
EG/HI	1	1	1	3			4

From Table 6 it is evident, that most states use HI sheeting for Warning and Regulatory red signs (Stop signs, etc.). Some states require HI sheeting for all overhead and/or interstate signs. SE is not very common. California and Oklahoma specify SE sheeting as the recommended option for Guide signs. Pennsylvania uses SE for Regulatory red signs.

4 - Minimum Reflective Requirements

Only 46 % of the respondents answered that they have minimum reflectivity requirements for new sign sheeting materials. Approximately 14% of the respondents who answered no, provided a specification anyway. Table 7 summarizes the answers.

TABLE 7. MINIMUM REFLECTIVITY REQUIREMENT.

Answer	Number of States	Percentage
Yes	17	47
No, but show spec.	5	14
No Requirement	13	36
No Answer	1	3
Total Responses	36	100

TABLE 5. TYPES OF SIGN SHEETING MATERIALS USED FOR DIFFERENT SIGN CLASSES

STATE	Regul. Red	Regul. Other	Warning	Guide	Constr./Maint.	Information	Miscellaneous	Overhead	Interstate
Arizona	E	E	E	E - H (int.)	H	E	E		H (guide)
Arkansas	H	E	H (D)	E			E		H (D)
California	H - S	H - S	H	S	H				
Colorado	H	H	H	H	E - H				
Connecticut	E	E	E	E M- H (large)	H	E			
Delaware	H (D)	H (D)	H (D)	H (D)		E	E		
Florida	S - D - H	E	E	E				S - H - D	
Georgia	E	E	E	E					E/H
Idaho	H	E - S	E	E - H	H	E	E		E/H
Indiana	H	E	H	E - H (int.)	E - H	E- H (int) - S			mostly H
Kansas	H - E	H - E	H - E	H - E					
Louisiana	H	E	H - E	E/H (large) -E					H
Maine	E	E	E	E					E/H
Michigan	H	H	H	H	H	H			
Minnesota	mostly H	mostly H	mostly H	mostly H	H (D)	E - H			
Mississippi	mostly H	mostly H	mostly H	H/E					H
Missouri	H	E	E	E	E	E	E	H	
Montana	E	E	E	E	E	E	E	H	
Nebraska	H	H	H	H		H	E		
Nevada	H	H	H	H			H - E		
New Jersey	mostly H	mostly H	mostly H	mostly E		mostly E			
New York	H	H	H	H		E			
North Carolina	E/H	E/H	E/H	H/E				H	H
Ohio	H	E	mostly E	E	H			H	mostly H
Oklahoma	H	H	H	S			S - E(f.vand.)	H	
Oregon	H	H	H	H					
Pennsylvania	S	E	E - H	E - H (freew.)					
South Carolina	E - H	E - H	E	E - H					
Tennessee	H	H	H	H			H -E		
Texas	H	E	H	mostly E	H				
Utah	H	H	H	H					
Vermont	H	E	mostly H	E				H	
Virginia	H	H	H	H		H - E/H			
West Virginia	E	E	E - H	E					H
Wisconsin	E	E	E	H					
Wyoming	E	E	E	E	H				E/H

NOTES: E = Engineering Grade S = Super Engineering H = High Intensity E/H = E background with H legend

The most commonly used standard for minimum retroreflectivity requirements is FP-85. The standards used by each state are shown in Table 8. The distribution of the percentage of states that responded affirmatively, that use each standard is shown in table 9.

TABLE 8. STANDARDS USED BY RESPONDENT STATES.

State	Reflectivity Standards Used					
	Has Minim. Requirement?	FP-85	AASHTO	ASTM	Own Standard	Response No clear
Arizona	Yes				X (1)	
Arkansas	Yes	X				
California	Yes	X				
Colorado	Yes			X		
Connecticut	No					
Delaware	Yes					X
Florida	Yes	X				
Georgia	No					
Idaho	Yes	X				
Indiana	Yes		X			
Kansas	No					
Louisiana	No					
Maine	No					
Michigan	Yes	X				
Minnesota	No		X			
Mississippi	No					X
Missouri	Yes			X		
Montana	Yes	X				
Nebraska	No					
Nevada	No					
New Jersey	Yes/Proposed				X	
New York	No					
North Carolina	No					
Ohio	No					X
Oklahoma	Yes	X				
Oregon	---					
Pennsylvania	Yes				X	
South Carolina	Yes		X			
Tennessee	No					
Texas	Yes				X	
Utah	No				X	
Vermont	No					
Virginia	No		X			
West Virginia	No					
Wisconsin	No	X				
Wyoming	Yes	X				

(1) AASHTO + HI Brown Sheeting

TABLE 9. COMMONLY USED SIGN SHEETING MATERIAL STANDARDS.

Standard	Number of States	Percentage
FP-85	9	39
AASHTO	4	17
ASTM	2	9
Own Standard	5	22
No Clear Answer	3	13
Total Responses	23	100

Although there are some differences in minimum SIA requirements between the different standards (especially for engineering grade sheeting), these differences are minimal. A comparison of the different standards is shown in APPENDIX II.

Some states also require minimum retroreflective values after a predetermined number of years, but these values are based on manufacturer's warranties. The requirement is used mainly for quality assurance.

5 - Sign Inventory and Computerized Database.

Approximately one third of the respondents had a current inventory of in-service traffic signs, as shown in Table 10. Of the states with a current sign inventory, all but two used a computerized database. The frequency of updating varied widely, from daily to annually.

TABLE 10. NUMBER OF STATES HAVING SIGN INVENTORY.

Answer	Number of States	Percentage
Yes, has sign inv.	13	36
Do not have	21	58
Proposed	2	6
Total Responses	36	100

McGee reported that in a 1990 survey, 15 of 48 states had sign inventories (10).

6 - Maintenance Activities

The most common maintenance activity reported was replacement of signs due to knock-down, vandalism or aging. A few respondents reported that they perform sign cleaning and sign overlays.

7 - Sign Inspection

The reported frequencies of inspection are summarized in Table 11. In all cases, inspections are routinely performed visually. Some respondents indicated that they perform night inspections. A few states perform partial retroreflective testing.

TABLE 11. INSPECTION FREQUENCIES.

Frequency	Number of States	Percentage
No scheduled	12	33
Annual	12	33
Semiannual	8	22
Quarterly	1	3
Monthly	1	3
Other	2	6
Total Responses	36	100

8 - Minimum Reflectivity Requirements for Sign Maintenance.

None of the respondents had minimum threshold SIA values for sign maintenance or replacement. Most states performed visual inspections to determine if signs should be replaced or overlaid. A few states use retroreflectivity measures, but not on a routine basis. The respondents that used the more common methods are shown in Table 12.

TABLE 12. METHODS USED TO DETERMINE SIGN LACK OF REFLECTIVITY.

Method	Number of States	Percentage
Only visual inspection	27	75
Q-beam/spotlight	3	8
Retroreflectivity	2	6
Replacement based on life-expectancy	4	11
Total Responses	36	100

9 - Retroreflectivity Measurement Equipment

Approximately 78 % of the surveyed states reported to have at least one piece of equipment for measuring retroreflectivity. The manufacturers listed are summarized in Table 13.

TABLE 13. MAJOR RETROREFLECTOMETER MANUFACTURERS.

Manufacturer	Number of pieces
Advanced Retro Technology	20
Gamma Scientific	10
Spectra Pritchard	2
Gardner Ind.	1
ESNA	1
Mirolux	1
Tektronic	1

The most common manufacturer is Advance Retro Technology (ART). The portable 920 ART Retroreflectometer is the most commonly used model.

10 - Major Sign Sheeting Manufacturers

According to the survey, the major sheeting manufacturer is 3M, followed by Avery/Fasson and Seibulite (formerly Seibu Mitsubishi). The number of agencies using each manufacturer's products is listed in Table 14.

TABLE 14. MAJOR SHEETING MANUFACTURERS.

Manufacturer	Product	Number of States	Percentage of Respondents
3M	Scotchlite	36	100
Avery/Fasson	Fasing	19	53
Seibulite	Seibulite	14	39
Mitsubishi	Seibulite	1	3
Reflexite	Reflexite	4	11
Amerace/Stimsonite	Stimsonite	3	8
Nippon Carbide	Reflexite/Stimsonite	2	6
Kiwalite	Kiwalite	1	3

III.3 - SUMMARY

The number of sign classes used varies widely. However, most state sign classifications include the MUTCD classes.

High Intensity Grade sheeting is the most used sheeting type, followed by Engineering Grade sheeting. Super Engineering sheeting is less used. Only California and Oklahoma specify SE sheeting as the recommended option for Guide signs. Pennsylvania recommends SE for Regulatory red signs.

Most states have a policy, establishing the type of sheeting used for each sign class. However, none have established minimum retroreflective requirements based on the driver's visibility.

Sixty percent of the responding states have minimum retroreflectivity requirements for new sheeting material. The standards used by the states are very similar.

Approximately one third of the respondents have a sign inventory maintained in a computerized database. Visual inspections are performed by most states on a variable basis.

The most common piece of equipment used to measure retroreflectivity is the portable ART Reflectometer Model 920.

The major sheeting manufacturer is 3M, followed by Avery/Fasson and Seibulite (formerly Seibu Mitsubishi).

IV - MINIMUM REFLECTIVITY REQUIREMENTS

A traffic sign must transmit its information to a driver before the driver's vehicle gets to the sign. The sign must be located to allow the driver to perform any required maneuvers in a safe and timely manner. Two distances are involved in the driver-sign interaction:

1. The distance at which the transmission of the information must occur to allow the driver to recognize the sign and react in consequence if necessary, and
2. Sign visibility, or the maximum distance at which the sign can be detected.

At night, visibility distance is largely dependent on sign retroreflectivity. Therefore, signs must provide a minimum retroreflectivity to assure that the visibility distance required by the driver is achieved.

IV.1 - DRIVER REQUIREMENTS

In general, a driver must be able to accomplish the following steps before reaching the sign (11):

1. Detect the sign,
2. Recognize it,
3. Make an appropriate decision, if necessary,
4. Initiate a maneuver, and
5. Complete the maneuver

The distance required by the driver can be computed by estimating the time required for each action. Then each estimated period of time can be transformed into distances using the appropriate vehicle speed.

Some signs do not require a maneuver or driver response (such as "No Left Turn") but they still have to be seen, recognized and interpreted. Based on the actions required before reaching the sign, traffic control devices can be grouped into four categories (Perchonok and Pollack, 1981):

- Class I: the driver must accomplish all critical steps before reaching the sign.
- Class II: the driver must accomplish all but the maneuver stage before reaching the sign. There are a few signs in this class, such as "Turn Off 2-Way Radios."
- Class III: the driver must detect and recognize the sign and make a decision before reaching the sign.
- Class IV: the driver must only detect and recognize the sign.

The recognition and detection distances are different for each sign class. Perchonok and Pollack suggested detection and recognition distances for some of the most common signs (11). The distances are shown in Tables 15 and 16.

TABLE 15. DETECTION DISTANCES (FT.) (11).

Sign Type	Travel Speed (mph)		
	30	45	60
No Left Turn Two Way Traffic ONE WAY	161	241	321
DO NOT PASS DETOUR AHEAD WRONG WAY	205	307	409
STOP (AW)	233	430	681
STOP	312	549	839
YIELD (AW)	321	562	857
School Crossing	365	628	945
YIELD	400	681	1015

NOTE: (AW) = includes advanced warning

TABLE 16. RECOGNITION DISTANCES (FT.) (11).

Sign Type	Travel Speed (mph)		
	30	45	60
No Left Turn Two Way Traffic ONE WAY	66	99	132
DO NOT PASS DETOUR AHEAD WRONG WAY	110	165	220
STOP	218	407	650
School Crossing	350	605	914
YIELD	306	539	826

IV.2 - VISIBILITY DISTANCE

Visibility distances of traffic signs must be larger than those required by the driver. At night, visibility is largely affected by the retroreflectance of the traffic sign. Other factors that affect the distance are:

1. Sign color,
2. Sign size,
3. Level of surrounding complexity,
4. Internal contrast, and
5. Driver's vision (generally related to the driver's age).

Coulomb and Michaut studied the relation between visibility distance and Coefficient of Retroreflection (R'). They concluded that R' is only one of the parameters involved. Other factors such as the dimension of the letters, cleanliness of head lights, or weather conditions can influence visibility distance (12).

Mace and Pollack performed laboratory and field studies reported on the visual complexity of sign surroundings and its relationship to sign detection. They found that visual complexity can be as important as brightness or contrast in sign visibility. The field study showed that increasing sign brightness could offset the effects of visual complexity (13). They also found that visual complexity is very difficult to quantify due to the many variables involved. Mace et al. proposed a procedure for categorizing visual complexity based on subjective rating of sign locations on 4 separate scales. The scale values from the 4 scales are added and the resulting number is the site is visual complexity value. (14).

A driver's age also has a major impact on detection and recognition distances, because older drivers (over age 65) on the average have less visual acuity than younger drivers (less than age 49) (15). The percentage of older drivers driving during the night is an important factor to take into account when establishing minimum retroreflectivity requirements.

Olson (16, 17) conducted a field study of sign conspicuity, measuring the distances at which subjects could distinguish and identify the color of test sign panels. The signs had different levels of retroreflectance and were located on public roads with different levels of environmental complexity. The study considered four independent variables:

1. Level of retroreflective efficiency (SIA),
2. Sign color (yellow was the primary color used),
3. Level of visual complexity of the surroundings, and
4. Driver's age group.

In this study, subjects were asked to drive through selected road sections with different surrounding complexities The signs (30 inch square) were placed at random points along the roadside. The distances from the sign to the point where the subject detected the sign and correctly recognized the color were measured. All independent variables were found to affect sign conspicuity:

1. The data indicate that older drivers require signs with at least three times greater SIA than younger subjects to achieve equivalent performances.
2. Colors red, orange, green and blue have substantially greater conspicuity than yellow (and possibly white) with equivalent retroreflectivity. However, sign color within the same family of materials or sheeting grade (for example, EG) appears to have the same conspicuity. As this result was not anticipated, the effect of color could not be accurately quantified.
3. Signs located in high complexity areas require as much as 10 times more retroreflectivity than those located in low complexity surroundings.

Based on the field study results, a relation between SIA and the identification distance was developed for yellow warning signs placed in different surrounding complexity levels. The SIA values were computed to satisfy the requirements of 85% of the study's drivers. A correction factor (0.6) to accounts for the driver's expectancy during the experiment was applied to the measured identification distances. The corrected curves for the 3 complexity levels are shown in Figure 3. The values recorded in the study corresponded to identification distances, or response distances, for signs leaving no choice of response to the driver (such as STOP signs).

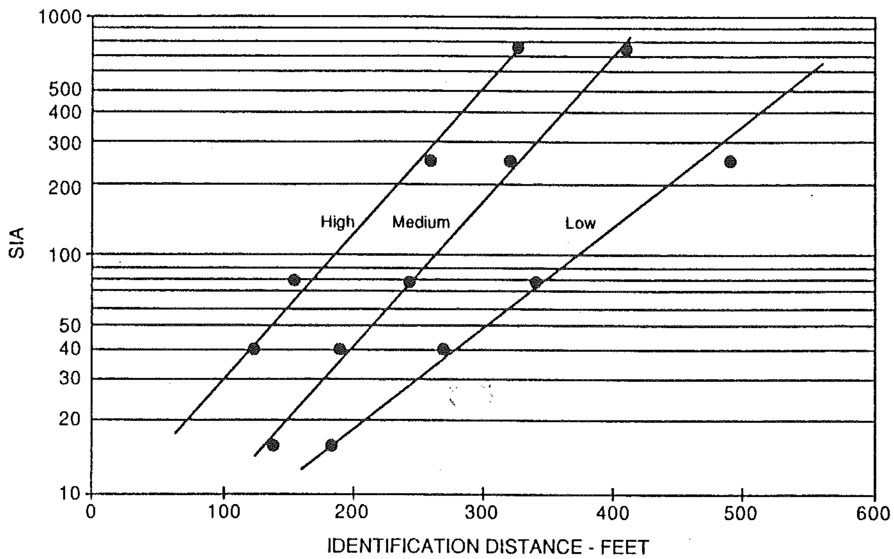

Figure 3. Eighty-Fifth Percentile Yellow Warning Sign Identification Distances (17).

IV.3 - RETROREFLECTIVITY REQUIRED TO FULFILL VISIBILITY NEEDS

As night visibility for highway signs is heightened primarily by retroreflection, there should be a minimum retroreflectivity requirement that assures the visibility distance required by the driver. Though the highest possible SIA would seem desirable, consideration must be given to glare and legibility problems due to excessively high retroreflectance. Life-cycle cost must also be taken into account.

Currently, minimum reflectivity requirements (SIA) only exist for purchase of new signs and new sign sheeting. But these requirements are related to the manufacturer's warranties and were not established based on driver needs for sign legibility. Several sign legibility studies have recently been conducted and the results of these studies may prove helpful in assessing these needs. In particular the FHWA is involved in a project that will establish minimum retroreflectivity requirements for in-place interstate network signs.

Sivak and Olson conducted a literature review and recommended optimal and minimum luminance levels for retroreflective highway signs manufactured using engineering grade sheeting material. Eighteen experiences regarding the legibility of a message on a sign were included in the review. Researchers used the fact that, generally, legibility is an inverted U-shaped function of luminance. The optimum luminance is at the crest of the function (18). They recommended:

1. A replacement (minimum) background luminance of 16.8 cd/m^2, based on the 85th percentile. The optimum luminance value was 75 cd/m^2.
2. An internal contrast ratio of 12:1, between background and legend, for fully reflectorized signs.
3. Correction factors for the required luminance to account for other contributing variables. For example, researchers suggested a correction factor of 20 for high-luminance

surroundings and a factor of 2 to 5 for truck drivers, who typically have a larger observation angle.

The large correction factors recommended reflect the uncertainty involved in the determination of luminance requirements. It is important to note that this study only considered legibility. There must be a balance with other properties such as conspicuity and color detection to establish final optimum and minimum luminance values.

P. Olson, at the University of Michigan, recommended minimum SIA values for various sign types. Olson used the relationship between visibility distance and retroreflectance (SIA) determined in field studies together with required response distances based on those suggested by Perchonok and Pollack. Four types of signs were considered (17):

1. Stop signs
2. Warning signs (with number of possible choices)
3. Overhead Guide signs, and
4. Construction area signs (for two levels of traffic).

Several assumptions were made to draw the recommendations (17):

1. All materials within the same type (such as EG) have the same conspicuity, although they have very different SIA values. For example, red EG sheeting of 14.5 SIA will be equally conspicuous as white EG sheeting of 70 SIA.
2. Sign backgrounds determine sign conspicuity. The recommended SIA values are for a given sign background.
3. For signs with a black legend, 15% of black was assumed and the required retroreflectivity was multiplied by 1.15.
4. For colored (red, green or blue) signs with a white legend and borders, the increase in luminance due to the white surface area was not considered. It was assumed that the benefits of a colored background outweigh the contribution of the white areas.

Recommended values, principally for high complexity areas, appear to be high compared with current minimum SIA values specified for different common sheeting materials.

The recommended SIA values for different traffic signs and conditions are shown in tables 17 through 20.

1 - Stop Signs

Stop signs are Class I because the driver must complete a stop by the time the sign is reached. Also, since the vehicle must stop, it is the more critical red regulatory sign. Minimum recommended SIA values for different speeds and surrounding complexities are shown in Table 17 (17).

Morales using a similar approach, computed minimum SIA requirements for stop signs. He considered the average overall SIA of the sign (19). Although the retroreflectivity requirements are substantially lower than those computed by Olson (17), the results are relatively close to those recalculated by Olson using the overall SIA for low complexity surroundings, without the expectancy correction. Morales found no benefits for signs having SIA grater than 40.

TABLE 17. RECOMMENDED MINIMUM SIA VALUES FOR STOP SIGNS (17).

Speed (mph)	Area Complexity		
	Low	Medium	High
65	150	*	*
60	71	*	*
55	30	155	*
50	14	63	170
45	8	25	70
40	4	11	30
35	3	5	16
30	2	3	8

* Supplemental warning required.

*2 - **Warning Signs***

Most Warning signs are class III, meaning that the driver must detect, recognize and make a decision before passing the sign. If a response and maneuver are required, they can take place after the sign is passed. To develop minimum SIA requirements for yellow Warning signs, Olson considered the number of choices generated by the sign. The recommended SIA values are shown in Table 18 (17).

TABLE 18. RECOMMENDED MINIMUM SIA VALUES FOR WARNING YELLOW SIGNS (17).

Speed (mph)	Area Complexity						
	Low		Medium			High	
	Number of Choices		Number of Choices			Number of Choices	
	0-3	> 3	0-1	2-3	> 3	0-1	> 2
65	15	31	15	86	630	230	*
60	15	25	15	63	414	173	1115
55	15	21	15	52	276	144	750
50	15	17	15	38	180	110	520
45	15	15	15	29	126	80	345
40	15	15	15	23	80	63	230
35	15	15	15	17	52	52	150
30	15	15	15	15	35	38	100

* Supplementary devices required

*3 - **Overhead Guide Signs***

The suggestions shown in Table 19 for guide signs required more assumptions (17):

1. Correction for expectancy does not apply because the driver is searching for the sign.
2. Signs are typically larger than the test signs.
3. The level of illumination is considerably less than that of test signs (approximately 10%).
4. The driver must complete the reading task 100 ft. prior to the sign.

5. The reading time was estimated to be 3 words per second.

Legibility, which is very important for guide signs, was not considered in this approach.

TABLE 19. RECOMMENDED MINIMUM SIA VALUES FOR OVERHEAD GUIDE SIGNS WITH A GREEN BACKGROUND (17).

Speed (mph)	Area Complexity								
	Low			Medium			High		
	Words on Sign			Words on Sign			Words on Sign		
	3	6	9	3	6	9	3	6	9
70	8	15	27	13	31	70	35	82	200
60	8	13	22	12	25	54	32	70	150
50	7	11	17	11	20	37	28	54	100
40	7	9	13	10	15	25	25	40	68
30	6	8	10	8	12	17	22	33	46

4 - Construction Signs

Orange construction signs are commonly class I devices because a maneuver must be completed by the time the sign is reached. The computed retroreflectivity values are shown in Table 20 (17).

TABLE 20. RECOMMENDED MINIMUM SIA VALUES FOR CONSTRUCTION (ORANGE) SIGNS REQUIRING A LANE CHANGE (17).

Speed (mph)	Traffic Volume					
	Light to Medium			Medium to Heavy		
	Area Complexity			Area Complexity		
	Low	Medium	High	Low	Medium	High
≥45	*	*	*	*	*	*
40	170	*	*	*	*	*
35	95	425	*	240	*	*
30	51	230	*	114	*	*
25	28	98	280	57	250	*

* Advance warning required.

An approximation of the values for orange Class III Construction signs can be obtained by multiplying the values of Table 18 by 0.55 (17).

IV.4 - DETERIORATION OF TRAFFIC SIGNS

Retroreflective signs deteriorate with time, losing brightness, color and contrast. This causes a reduction in detection and recognition distances. While important, retroreflection loss is not the only factor that accounts for sign deterioration. Loss of contrast, fading or physical deterioration (cracking, peeling, crazing, dimensional changes, etc.) are other important factors.

The main factors that affect sign deterioration are (6):

1. Solar irradiation,
2. High temperature and water/moisture effects,
3. Photo-oxidation,
4. Industrial pollution, such as, acid rain, and
5. Wind erosion, sand abrasion and dirt and salt particles.

Sign vandalism is also an important factor in sign durability. As much as 30 % of sign replacement in the nation is due to vandalism (20).

Accelerated weathering tests, such as ASTM G-23, are specified as quality control requirements for most sheeting standards. These tests consist of exposing the material to artificial weathering produced by a weatherometer chamber that simulates sun irradiation, variable temperatures, rain and moisture. The sheeting must not show excessive physical deterioration and must maintain a percentage of its initial retroreflectivity after a determined number of hours of exposure. For example, FP- 85 requires that the material retain (using an ASTM G-23, Type E or EH weatherometer with the humidifier off) the following percentages of the minimum required SIA for new sheeting:

1. EG: 50% after 1,000 hours of artificial weathering
2. SE: 65% after 2,200 hours of artificial weathering
3. HI: 80% after 2,200 hours of artificial weathering

Ketola suggested that artificial accelerated exposure tests are inadequate for assuring durability of reflective sheeting. This suggestion, was based on comparisons between weathering test results and natural exposure tests performed in Arizona and Florida. He recommends outdoor exposure tests (21). Outdoor exposure test procedures are prescribed in ASTM G-7.

Deteriorated signs should be replaced before they reach critically low retroreflective values. The FHWA sponsored a study performed by BMI Inc., that determined performance prediction curves for the retroreflectivity of traffic signs (6). These curves allow the prediction of sign life based on current retroreflectivity measurements and can be used in a sign management system.

Some standards specify a minimum percentage of the original SIA that in-service signs must retain after a determined period of time (normally 7 or 10 years). These values are usually based on manufacturer's suggestions or research work. Some examples are:

1. Texas requires that sheeting retain a minimum SIA after years of exterior exposure as follows:
    - 60% after 3 years for EG,
    - 60% after 10 years for SE, and
    - 80% after 10 years for HI.

2. Ohio requires that the material retain:
    - 50% after 7 years for EG, and
    - 85% after 7 years and 80% after 10 years for HI.

High performance sheeting has been given a service life of 10 to 15 years and engineering grade a service life of 7 to 10 years. Telephone contacts with several Traffic Engineers in different states confirmed that normally the service life of in-place signs exceeds the life warranted by manufacturers.

Nettleton reported the test results of more than 7 years of natural exposure in very harsh environments. Several different sheeting materials were evaluated. The findings are summarized below (22):

1. 3M EG products performed well when applied with top edge tape.
2. 3M HI sheeting did not perform as well.
3. Amerace products (Stimsonite) showed early failure.
4. Avery products (Fasing) failed at the beginning, but performed well after being completely reformulated.
5. Reflexite products performed well.
6. EG and SE Seibulite products performed well.

The survey conducted for this study shows that a few states have sign replacement programs based on the life expectancy of the sign.

Black et al. evaluated retroreflectivity of more than 6,000 signs throughout the United States to determine predictive equations for sheeting retroreflectivity. Arizona was one of the states included in the study. Signs were divided by sheeting type, color, age and geographic location. Orientation and ground elevation were also considered in the analysis. A prediction equation was developed for each sheeting type (engineering grade and high performance) and color (red, yellow, white and green). The main findings of the study were (6):

1. A prediction equation can be proposed for each sheeting material and color, as shown in Table 21. It is important to note that the prediction equations forecast average retroreflectivity values for the entire population for each sign type and color. Approximately half of the total signs will have SIA measurements lower than the predicted SIA;
2. In general, for even the oldest signs almost all mean SIA values (for each color and sheeting type) collected exceeded the minimum retroreflective level specified in FP-85 for new materials. The only exception was the red HI sheeting;
3. Variations in the coefficient of retroreflection within each group were very large, even for new signs. Consequently, the accuracy of the equations is limited.
4. The age variable was the dominant predictor in all cases; and
5. A unique behavior was found in red signs, since SIA values decrease first, but then start to increase after a period of time. Since many red signs are manufactured using white sheeting with transparent red copy, the increase in retroreflectivity may be due to fading of the red ink.

One weak point of the study was the excessively large variance found within each color for the same age group. The applicability of the equations can be questioned due to this fact.

TABLE 21. PREDICTION EQUATIONS FOR SIGN RETROREFLECTIVITY (SIA) (6).

Sign Type		Predictive Equation
Red	EG	SIAp = 21.466 - 1.269(AGE) - 0.0004(DEG DAYS) + 0.124(PRECIP) + 0.0003 (ELEV)
AGE≤3	HI	SIAp = 38.97 - 3.574(AGE) + 0.0001(DEG DAYS) + 0.240 (PRECIP) - 0.001(ELEV)
AGE≥5		SIAp = 19.765 + 2.496(AGE) - 0.00003(DEG DAYS) + 0.067(PRECIP) + 0.0001(ELEV)
Yellow	EG	SIAp = 78.794 - 3.906(AGE) + 0.002 (DEG DAYS) + 0.115(PRECIP) + 0.002(ELEV)
	HI	SIAp = 247.850 - 4.578(AGE) - 0.001(DEG DAYS) + 0.174(PRECIP) + 0.002(ELEV)
White	EG	SIAp = 103.085 - 5.451(AGE) + 0.002(DEG DAYS) + 0.178(PRECIP) + 0.002(ELEV)
	HI	SIAp = 304.089 - 4.815(AGE) + 0.002(DEG DAYS) + 0.06(PRECIP) + 0.001 (ELEV)
Green	EG	SIAp = 15.990 - 0.637(AGE) + 0.0003 (DEG DAYS) - 0.036 (PRECIP) + 0.0001(ELEV)
	HI	SIAp = 53.386 - 1.345(AGE) - 0.002(DEG DAYS) + 0.337(PRECIP) + 0.003 (ELEV)

Notes:
SIA_p = Predicted Coefficient of Retroreflection (SIA).
AGE = Age category of sign sheeting in years.
PRECIP = Annual precipitation in inches.
DEG DAYS = Annual heating degree days.
ELEV = Average ground elevation in feet.

IV.5 - REQUIRED SHEETING GRADES

McNees and Jones studied legibility distances for unlighted Overhead Guide signs. They found that the combinations of background/legend sheeting materials that provide the best legibility were (23):

1. High Intensity (HI) background with HI copy,
2. Opaque background with Button copy, and
3. Engineering Grade background with button copy.

Button copy refers to removable letters, with plastic retroreflective devices that are used to compose sign legends of guide signs. It should be noted that the study used existing signs and did not consider the influence of other factors such as sign age or surrounding visual complexity.

McGee found that all 3 types of sheeting are currently being used by the states for Guide sign background. HI copy or button copy is generally used for the copy (10).

Ahmed conducted a study to determine the type of retroreflective sheeting most appropriate for construction site traffic control devices. He found that the trade off between detectability and legibility favored Super Engineering Grade (SE) sheeting material, on both urban and rural highways. Nevertheless, HI sheeting was recommended for locations with high visual complexity. With HI materials, some drivers reported glare problems due to excessive luminance and some construction companies reported durability problems. The findings were not very strong due to the large variability of driver's responses (24).

McGee and Mace provided general guidelines for selecting the most appropriate sheeting type based on visibility requirements (2):

1. EG provides adequate service for all permanent signs in many situations,
2. SE or HI is desirable for Class I Regulatory signs in high speed areas (with a posted speed of 45 mph or greater),
3. SE or HI is desirable for all critical signs (Regulatory, Warning or Guide) in any visually complex situation,
4. HI is desirable for all signs placed on the left side of a two-way road (such as NO PASSING ZONE signs),
5. EG or HI (type FP-85 III-A) is suggested for signs requiring wide angular viewing, and
6. HI is desirable for work area signs. SE is adequate for channelization devices. However, for durability purposes HI reboundable sheeting may be required.

Using Olson's recommended minimum SIA values (17), and considering retroreflectivity values specified by FP-85 for each sheeting type, the minimum grade of sheeting necessary for several traffic sign types was estimated. The assigned SIA value (for 0.2° observation and -0.4° entrance angles) for each sheeting color and grade was the minimum retained retroreflectivity required after the warranted service life, as shown below:

1. 50% of initial requirement for EG,
2. 65% for SE, and
3. 80% for HI.

For example, in a low complexity zone, with posted speed of 50 mph, a SIA value of 14 is required for a STOP sign. Therefore, both SE and HI would be appropriate, but SE is the minimum required.

1 - Stop Signs

The retroreflectivity values suggested by Olson for high speed highways (17) can not be attained with common materials currently used. In this case, new materials (such as Diamond Grade sheeting), larger signs or supplemental warning devices should be employed.

In general, EG is only appropriate in low or medium complexity areas with low posted speeds (less than 40 mph). HI sheeting would be appropriate for speeds as high as 55 mph in low complexity areas, but in complex environments HI is acceptable only for 40 mph or less. The minimum required grades for each condition are shown in Table 22.

TABLE 22. MINIMUM SHEETING GRADE NECESSARY FOR STOP SIGNS.

Speed (mph)	Area Complexity		
	Low	Medium	High
65	a	*	*
60	a	*	*
55	HI	a	*
50	SE	a	a
45	SE	HI	a
40	EG	SE	HI
35	EG	EG	SE
30	EG	EG	SE

a - Required SIA exceeds retroreflectivity of standard red sheeting.
* - Supplementary warning required.

2 - Warning Signs

According to Olson's conclusions for low complexity areas (17), EG is appropriate for almost all speeds and numbers of choices. EG is also appropriate in medium complexity areas with 0 or 1 possible choices. For high complexity areas, if only one choice is possible, speeds of 55 mph or more require brighter materials, illumination or larger signs. For more choices, brighter materials, illumination or larger signs are required for speeds as low as 35 mph. Minimum required grades for each condition are shown in Table 23.

TABLE 23. MINIMUM SHEETING GRADE REQUIRED FOR WARNING YELLOW SIGNS.

Speed (mph)	Area Complexity						
	Low		Medium			High	
	Number of Choices		Number of Choices			Number of Choices	
	0-3	> 3	0-1	2-3	> 3	0-1	> 2
65	EG	SE	EG	HI	a	a	a
60	EG	EG	EG	SE	a	a	a
55	EG	EG	EG	SE	a	a	a
50	EG	EG	EG	SE	a	HI	a
45	EG	EG	EG	SE	HI	HI	a
40	EG	EG	EG	EG	HI	SE	a
35	EG	EG	EG	EG	SE	SE	a
30	EG	EG	EG	EG	SE	SE	HI

a - Required SIA exceeds retroreflectivity of standard grade sheetings.

Mace et al. suggested that FP-85 Type II yellow sheeting degraded to 36% of specification (SIA=18) is appropriate for low complexity areas. For medium complexity areas, researchers suggested a minimum SIA of 36. Finally, for high complexity areas researchers suggested HI materials (14). These results are relatively close to the ones in Tables 18 and 23.

3 - Overhead Guide Signs

Minimum required grades for each condition are shown in Table 24. According to Olson's conclusions (17), EG sheeting is not appropriate for overhead guide signs. SE sheeting appears appropriate in low complexity areas and medium complexity areas with 3 or fewer words. In high complexity areas HI is required, and supplementary devices are needed if the sign has more than three words. Larger signs, illumination, or more retroreflective materials could be other options.

It is important to note that all the assumptions required to determine the retroreflectivity requirements listed previously still apply. In particular, consideration should be given to legibility if brighter materials are used. Other factors, such as different sign and legend sizes, should also be taken into account.

TABLE 24. MINIMUM SHEETING GRADE REQUIREMENTS FOR OVERHEAD GUIDE SIGNS WITH A GREEN BACKGROUND.

Speed (mph)	Area Complexity								
	Low			Medium			High		
	Words on Sign			Words on Sign			Words on Sign		
	3	6	9	3	6	9	3	6	9
70	SE	SE	HI	SE	HI	a	HI	a	a
60	SE	SE	HI	SE	HI	a	HI	a	a
50	SE	SE	SE	SE	SE	HI	HI	a	a
40	SE	SE	SE	SE	SE	HI	HI	a	a
30	SE	SE	SE	SE	SE	SE	HI	HI	a

a - Required SIA exceeds retroreflectivity of standard grade sheetings.

4 - Construction Signs

Minimum required grades for each condition are shown in Table 25. In most cases more than a single sign is required for construction areas. HI sheeting is required in almost all conditions.

TABLE 25. MINIMUM SHEETING GRADE REQUIRED FOR CONSTRUCTION SIGNS REQUIRING A LANE CHANGE WITH AN ORANGE BACKGROUND.

Speed (mph)	Traffic Volume					
	Light to medium			Medium to Heavy		
	Area Complexity			Area Complexity		
	Low	Medium	High	Low	Medium	High
⑧45	*	*	*	*	*	*
40	a	*	*	*	*	*
35	a	a	*	a	*	*
30	HI	a	*	a	*	*
25	SE	a	a	HI	a	*

a - Required SIA exceeds retroreflectivity of standard grade sheetings.
* Supplementary devices required.

5 - Regulatory Class III Signs

Since sheeting materials are supposed to have the same conspicuity within the same grade, the recommendation for yellow warning sign, shown in Table 23 can be applied to this group.

6 - Ground Mounted Guide Signs

For ground mounted guide signs, a rough estimation of required SIA can be made by removing the illumination and size correction factors applied by Olson to compute the required SIA for Overhead Guide signs. This procedure results in required SIA values approximately one fourth of those required for Overhead signs (showed in Table 19). Estimated required grades are shown in Table 26.

TABLE 26. MINIMUM SHEETING GRADE REQUIREMENTS FOR GROUND MOUNTED GUIDE SIGNS WITH GREEN BACKGROUND.

Speed (mph)	Area Complexity								
	Low			Medium			High		
	Words on Sign			Words on Sign			Words on Sign		
	3	6	9	3	6	9	3	6	9
65	EG	EG	SE	EG	SE	SE	SE	SE	a
55	EG	EG	SE	EG	SE	SE	SE	SE	HI
45	EG	EG	EG	EG	EG	SE	SE	SE	HI

7 Summary

Based on all the recommendations above, the required sheeting grades for three speed levels (45, 55 and 65 mph) and two complexity areas (low and high) are summarized in Table 27. Construction signs should be fabricated with HI materials in all cases. More than a single sign is required in almost all cases. In the cases where supplemental devices are required, advanced warning, larger signs, illumination or brighter materials are possible solutions depending on the case.

TABLE 27. REQUIRED SHEETING GRADES FOR DIFFERENT SIGN TYPES.

Type of Sign	Sheeting Type					
	Low Complexity			High Complexity		
	45 mph	55 mph	65 mph	45 mph	55 mph	65 mph
Regulatory Class I	SE	HI	HI (*)	HI (*)	HI (*)	HI (*)
Regulatory Class III	EG	EG	EG	HI (1)	HI (*)	HI (*)
Warning	EG	EG	EG	HI (1)	HI (*)	HI (*)
Overhead Guide	SE	SE	HI	HI (2)	HI (2)	HI (2)
Ground Mt. Guide	EG	SE	SE	HI	HI	HI (3)

(*) - Supplemental devices required.
(1) - Supplemental devices necessary if more than 2 choices are possible.
(2) - Supplemental devices necessary for more than 3 words.
(3) - Supplemental devices necessary for more than 9 words.

As mentioned before, the minimum SIA requirements appear to be high, compared with current practices. It is also important to note that available sheeting materials commonly exceed federal specifications for new materials after several years of field service.

IV.6 - FHWA PROJECTS

The Federal Highway Administration (FHWA) recognizes that some traffic control devices are not providing adequate visibility distance during nighttime (25). This fact is supported by statistics showing that fatality rates (fatalities/ vehicle-mile) are more than three times higher at night than during the day. To improve driving safety at night, minimum retroreflective requirements must be determined. As a consequence, a High Priority National Program Area (HPNPA) has been established. The goals of the HPNPA cooperative effort are to determine minimum retroreflectivity requirements and develop management programs and measurement devices necessary to implement the requirements.

Several individual projects are included in the HPNPA:

1 "Minimum Visibility Requirements for Traffic Control Devices": This project will determine minimum visibility requirement and the level of retroreflectivity required to satisfy the visibility requirements. This project could be a good reference point for establishing ADOT requirements.

2 "Implementation Strategies for Sign Retroreflectivity Standards" (NCHRP Report 346): Based on retroreflectivity measurements of more than 8000 signs nationwide, the economic impact of establishing minimum retroreflective requirements was estimated. Two possible sets of minimum standards (one in the lower part of the possible range and the other in the upper) and several implementation strategies (immediate, 3, 5 and 10 years) were evaluated. The findings show that current practices appear adequate to maintain the signs in the lower standard tested, but the economic impact of higher standards could be considerable. However, the use of brighter materials appears to reduce the amount of maintenance cost over time (26).

3 "Service life of Retroreflective Traffic Signs": This project determined deterioration prediction curves for different sheeting types and colors. It was described in section IV.4, "Deterioration of Traffic Signs".

4 "A Mobile System for Measuring Retroreflectivity of Traffic Signs" (NCHRP Project 5-10): A practical, safe, cost-effective instrument to measure sign retroreflectivity during the day from a mobile vehicle is being studied. The prototype MTSE was described in section II.2, "Equipment to Measure Retroreflectivity."

5 "Sign Management System" (SMS); FHWA's SMS is being improved to provide local agencies with a microcomputer-based predictive tool for use in managing a sign inventory. SMS will incorporate the results from the other individual projects. The resulting computer program will probably be public domain.

V - SUMMARY AND RECOMMENDATIONS

Retroreflection, or brightness, is an important factor that affects sign visibility at night. A traffic sign should provide enough retroreflectivity to allow drivers to detect and recognize the sign with enough time to react, if necessary.

Several national standards are available for new sheeting materials. All these specifications are similar. The main three sheeting types considered are Engineering Grade, Super Engineering Grade, and High Intensity.

The visibility distance of a sign must be larger than the distance required by the driver. The main factors that affect sign visibility or conspicuity are sign retroreflectivity, color and size, level of surrounding complexity, internal contrast and driver visual acuity.

A survey of 48 states was conducted to identify types of sheeting used and current usage policies. High Intensity Grade sheeting is the most commonly used type of sheeting, followed by Engineering Grade sheeting. Super Engineering sheeting is used less often.

Minimum retroreflectivity requirements are necessary to assure the required sign performance at night. Most states have a policy that establishes the type of sheeting to use for each sign class. However, none have established minimum retroreflective requirements based on a driver's visibility needs.

Sixty percent of the responding states have minimum retroreflectivity requirements for new sheeting material. The minimum reflectivity standards used by the states are very similar. The major sheeting manufacturer is 3M, followed by Avery\Fasson and Seibulite (formerly Seibu Mitsubishi).

A thorough literature review was performed to determine minimum retroreflectivity requirements to fulfill driver needs. Olson (1989) suggested minimum retroreflectivity for several types of signs. These requirements appear to be high compared with current practices.

Additionally, the FHWA is sponsoring a project that will recommend minimum retroreflectivity requirements for traffic signs based on driver needs.

Considering the economic impact of using more retroreflective sheeting materials and all the assumptions on which Olson's recommendations were based, it appears reasonable to wait for the results of the FHWA project "Minimum Visibility Requirements for Traffic Control Devices" before recommending a retroreflective sheeting policy for ADOT.

Additional research concerning recognition distances should also be considered. In particular, the study of the effects of color and size on sign conspicuity may be helpful.

Despite all of the mentioned limitations, Olson's recommendations were used to estimate the type of sheeting required for several sign classes (Table 27). The retroreflective sheeting policy that would result from applying these requirements can be summarized as follows:

1. HI is recommended for all signs in areas of high surrounding complexity (such as urban areas).

2. HI is recommended for Regulatory Class I signs and posted speeds over 45 mph. SE may be used in zones with speeds lower than 45 mph.
3. EG can be used for Warning and Regulatory Class III signs in low complexity (rural) areas.
4. Overhead signs should be manufactured with HI sheeting for freeways. SE can be used in low complexity areas with posted speeds below 55 mph and EG in zones with posted speeds below 45 mph.
5. HI should be used for Construction signs.
6. Supplementary devices, such as advanced warning, larger signs, illumination or brighter materials are required for:

   - Regulatory Class I signs in high complexity areas, and in low complexity areas with a posted speed of 65 mph.
   - Warning and Regulatory Class III signs in high complexity environments for posted speeds higher than 55 mph.
   - Overhead Guide signs in high complexity areas.
   - Ground-Mounted Guide signs in high complexity areas with a posted speed of 65 mph.
   - Construction Signs.

It should be noted that the policy shown above is not recommended for application, but is for reference only. It is recommended that ADOT wait for the guidelines of the FHWA on minimum retroreflectivity requirements before establishing a retroreflective sheeting policy.

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APPENDIX I

TRAFFIC SIGN SHEETING MATERIALS SURVEY

TRAFFIC SIGN SHEETING MATERIALS SURVEY

STATE	RESPONDENT IDENTIFICATION			SIGNS CLASSIFICATION									
	Name	Phone	Date	Clas. Scheme?	# of classes	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Arizona	Thomas Huey	602 255 6625	8/13/92	Y	10	Regulatory	Warning	Destination	Freew. Guide	Expr. Guide	Contruction	Adv. Constr.	Information
Arkansas	Jim Barnett	501 569 2231	9/20/91	N	--								
California	P.R. Lowden	916 654 4551		Y	4	Regulatory	Warning	Guide	Construction				
Colorado	J.D.Jessup	303 757 9436	9/23/91	Y	4	Permanent	Construction	Maintenance	Other C & M.				
Connecticut	Frank D'Addabbo	566 5110	12/18/91	Y	4	Regulatory	Warning	Guide & Inf.	Construction				
Delaware	John Barnes	302 739 4366	10/19/91	Y	8	Regulatory	Warning	Guide	Service	Recreational	Tourist	Civil Defense	State Parks
Florida	Joe Schaefer	904 488 4284	10/25/91	Y	3	Regulatory	Warning	Guide					
Georgia	Jerry Gosset	404 656 5314	9/27/91	Y	3	Type I	Type II	Major signs					
Idaho	Mark Jensen	208 334 8557	10/11/91	Y	6	Regulatory	Warning	Guide	Information	Constr./Main.	Misc.		
Indiana	Donald Scott	317 232 5540		Y	7	Regulatory	Warning	Guide	Construction	Destination	Information	Civil Defense	
Kansas	Arlen Tappan	913 296 3618	10/4/91	Y	3	Regulatory	Warning	Guide					
Louisiana	Francis Becnel	540 925 5719	10/3/91	Y	3	Regulatory	Warning	Guide					
Maine	Douglas McCobb	207 289 3775	9/27/91	N	--								
Michigan	Patrick Costigan	517 335 2860	9/19/91	Y	6	Regulatory	Warning	Guide	Construction	School	Information		
Minnesota	Michael Weiss	612 296 4002	10/9/91	Y	7	C (1)	D	A	EA	OH	EO	Overlay	
Mississippi	Jimmy Shirley	601 944 9333	10/9/91	?	--								
Missouri	David Snider	314 751 2785	9/17/91	Y	6	Regulatory	Warning	Guide	Service	Recreational	Const./Main.		
Montana	Patrick Brannon	406 444 6157	9/18/91	Y	15	Regulatory	Warning	Route marker	Scool	Rest area/Inf	Contr. acces	Gral. Inform.	Misc.
Nebraska	Dan WAddle	402 479 4594	9/17/91	N	--								
Nevada	P.D. Kiser	702 687 5406	10/2/91	Y	4	Regulatory	Warning	Guide	Other				
New Jersey	Frank Battaglia	609 530 3736	1/3/92	Y	7	Stop	No Stoping	Other Reg.	Cautonary	Directionary	Route Mark.	Misc.	
New York	Harry Sloan	518 457 4285	10/8/91	Y	3	Regulatory	Warning	Guide					
North Carolina	G. Glenn Grigg	919 250 4145	9/18/91	Y	5	mp. hs.	sp. hs.	sp. ws.	Reg. & Warm	Route Mark.			
Ohio	James Roth	614 644 8115	9/19/91	N	--								
Oklahoma	Wayne Russell	405 521 2867	9/18/91	Y	6	Regulatory	Warning	Guide	Overhead	Ground mount	Logo		
Oregon	Dwayne Hofstetter	503 378 6537	10/4/91	Y	23								
Pennsylvania	Robert Doughty	717 787 3620	9/30/91	Y	3 (*)	Regulatory	Warning	Guide					
South Carolina	Richard Wers	803 737 1462	10/24/91	Y	6	Regulatory	Warning	Guide	Information	Constr./Main.	School		
Tennessee	Joe Holt	615 741 2466	9/24/91	N	--								
Texas	Cathy Wood	512 465 6394	9/27/91	Y	4	Regulatory	Warning	Guide	Construction				
Utah	Fred Lewys	801 965 4285	9/20/91	Y	3 (*)	Regulatory	Warning	Guide					
Vermont	Ronald Borland	802 828 2680	9/23/91	N	--								
Virginia	T. Lee	804 786 6612		Y	3	Regulatory	Warning	Guide					
West Virginia	Ken Kobetsky	304 348 3063	10/8/91	N	--								
Wisconsin	Peter Rusch	608 266 0318	10/4/91	Y	4	Overh. Guide	(2)	Small Guide	Large Guide				
Wyoming	Mike Gostovich	307 777 4492	9/17/91	N	--								

NOTES:

Y = Yes
N = No
P = Proposed
? = Do not underestand the question
(*) MUTCD, not clear how many

sp. = Single panel
sp. = Single panel
mp. = Multi panel
hs. = Horizontal stringles
ws. = Without stringles

(1) Reg., Warn. & Guide
(2) Warning, Regulatory, Information and Standard size Guide

TRAFFIC SIGN SHEETING MATERIALS SURVEY

STATE	TYPES OF SHEETING MATERIAL USED					USAGE		REFLECTIVITY	
	# of Grade used	Grade 1	Grade 2	Grade 3	Grade 4	Usage Police ?	Description	Minimum Requir.?	Description
Arizona	4	Eng.	HI Lens.	HI Prism. (D)	Opaque	Y		Y	AASHTO (1)
Arkansas	3	Eng.	HI Lens.	HI Prism. (D)		Y		Y	FP-85
California	2	Sup. Eng.	HI			Y		Y	review
Colorado	3	Sup Eng.	HI Lens	Vinyl		Y		Y	ASTM
Connecticut	2	Eng.	HI Lens.			Y		N	
Delaware	3	Eng.	HI Lens.	HI Prism. (D)		Y		Y	attached
Florida	3	Eng.	Sup. Eng.	HI Lens.		Y		Y	attached
Georgia	2	Eng.	HI Lens.			Y		N	
Idaho	3	Eng.	Sup. Eng	HI Lens.		Y		Y	FP-85
Indiana	4	Eng.	Sup Eng.	HI Lens.	HI Prism.	Y		Y	attached
Kansas	2	Eng.	HI			Y		N	
Louisiana	2	Eng.	HI Lens.			Y		N	
Maine	2	Eng.	HI			N	(*)	N	
Michigan	1	HI				N		Y	FP-85
Minnesota	2	Eng.	HI			N		N	(*) AASHTO
Mississippi	2	Eng.	HI Lens.			Y		N	(*) no maint.
Missouri	2	Eng.	HI			Y		Y	attached
Montana	4	Eng.	Sup Eng.	HI	Reflexite	Y		Y	attached
Nebraska	2	Eng.	HI			Y		N	
Nevada	2	Eng.	HI			Y		N	
New Jersey	2	Eng.	HI			Y		Y/P	attached
New York	2	Eng.	HI			Y		N	
North Carolina	2	Eng.	HI Lens.			Y		N	
Ohio	2	Eng.	HI			Y		N	(*) attached
Oklahoma	3	Eng.	Sup. Eng.	HI		Y		Y	FP-85
Oregon	1	HI				Y		—	
Pennsylvania	3	Eng.	Sup Eng.	HI		Y		Y	attached
South Carolina	2	Eng.	HI			Y		Y	AASHTO
Tennessee	2	Eng.	HI			Y		N	
Texas	2	Eng.	HI			Y		Y	attached
Utah	1	HI Lens				N		N	
Vermont	3	Eng.	Sup Eng.	HI Lens.		Y		N	
Virginia	3	Eng.	HI Lens.	HI Prism. (D)		Y		N	(*) attached
West Virginia	2	Eng.	HI			Y		N	
Wisconsin	2	Eng.	HI			Y		N	(*) AASHTO
Wyoming	2	Eng.	HI Lens.			Y		Y	attached

NOTES:

Eng. = Engineering Grade (Type II FP-85)
Sup. Eng. = Super Engineering Grade (type II-a FP-85)
HI Lens. = High Intensity Grade, encapsulated lenses (type III-A FP-85)
HI Prism. = High Intensity, Prismatic (type III-B FP-85)
HI Prism. (D) = High Intensity, Diamond Grade

(1) Add Brown HI sheeting

TRAFFIC SIGN SHEETING MATERIALS SURVEY

STATE	MAINTENANCE, INVENTORY AND ACTIVITIES									
	Inventory ?	Comp. DB. ?	Freq. Update	Activ. 1	Activ. 2	Activ. 3	Activ. 4	Inspection Freq.	Description	Minimum Reflectivity
Arizona	N	Y	daily	—				A	visual	visual inspection
Arkansas	N	N		Replacement sign	Replace sign and post	Paint post	Replace post	M	night visual	visual insp./life expect.
California	N	N		Replace knock./vand.	Replace used	Change"Adopt a High."		S	one day & one night	subjective
Colorado	Y	Y	W	Replacement weathering	Update Sign	TODS	Change"Adopt a High."	Q	visual check	night/ Q-Beam daytime
Connecticut	Y	Y	as needed	—				N		complains/damage/etc.
Delaware	N	N		Installation New sign	Replacement	Straighten sign post		no sch.	day & some night	visual inspection
Florida	N	N		Inspections				A		Visually at night
Georgia	N	N		Replacement	Maintenance	Washing	Interstate s. overlay	S	drive thru	subjective
Idaho	Y	Y	D	Cleaning	Retamping	Replace post/sign	overlay	S	day & night visual	visual / retroreflect.
Indiana	Y	Y	varies	Repair knockdown	Replace signs	Straighten leaning	Upgrade on 10-year progr	no sch.	visual inspection	visual insp./10-year
Kansas	N	N		Replacement	Post Replacement	Inspections		S	nightime visual	subjective
Louisiana	N	N		Replace knockdown	Replace vandalism	Replace deteriorated	Reinstall	no sch.		visual inspection
Maine	Y	N		Replacement TODS	Replacement signs	Updating signs		A	drive by	visual inspection
Michigan	Y	Y	D	Replace knock./vand.				no sch.		No. 10/15-year
Minnesota	N	N		Replace stolen	Replace damaged	Replace vandalism	Straighten sign post	A (partial)	night	visual night/10-year
Mississippi	N	N		Replace knockdown	Reinstall signs missing	Replace signs vand.	Replace signs deter.	no sch.		Spot light daytime/visual
Missouri	Y	Y	A	Sign logs				A	sign condition	night inspection
Montana	Y	Y	D	Replacement	Install	Clean	Overlay	S	Refl./cond./post	visual inspection
Nebraska	N	N		Sign replacement	Post replacement			no sch.	visual	day or night visibility
Nevada	N	N		Straight Post	Repositionsign face	Replacement		no sch.	drive-by	daytime visual
New Jersey	P	N		Replace knock down	Install new sign	Replace old sign	Checking condition	no sch.		Individual judgement
New York	N	N		—				1/2 years	night visual	subjective
North Carolina	N	N		Replacement				A	daytime (part at night	visual inspection
Ohio	P	N		Replacement				A	driving night	2-3-4 rule
Oklahoma	N	N		Knockdown	Vandalism	End of service life		A	visual	engineer judgement
Oregon	Y	N		Replacement	Reinstallation			A	night visual	visual inspection
Pennsylvania	N	N		Inspection/Upgrade	Damage correction	Inspection		7-year+random	visual insp.	visual inspection
South Carolina	N	N		Remove & replace	Singning upgrade	New sign		A	day & night visual	desired standard
Tennessee	Y	Y	irregular	Sign replacement	Sign repair	Post replacement	Sign fabrication	no sch.	visual	Eng.judgement
Texas	N	N		Replace vandalism	Replace knockdown	Cleaning/Repositioning	Various	S	specified	nighttime
Utah	N	Y	no update	Replacement	Installation new sign			S	drive-by	Q-beam/ATR/night insp.
Vermont	Y	Y	W	Repair knockdown	Replace aged signs	Replace vandalized	Install new signs	A	visual insp.	visual inspection
Virginia	Y	Y	varies	—				S	visually, one at night	subjective
West Virginia	N	N		Replace sign	Replace post			no sch.	day or nighttime	visual night
Wisconsin	N	N		Repair Knockdown	Repair vandalism	Repair worn out	Upgrade to standards	A	by signing crews	appearance, some night
Wyoming	Y	Y	A	Repair	Replace	Refurbrish	New Installation	no sch.	nightly drive-by	visual insp./ 7-9 year

NOTES:
A = annual
D = daily
M = monthly
S = semiannual
Q = quarterly
W = weekly

TRAFFIC SIGN SHEETING MATERIALS SURVEY

STATE	REFLECTIVITY MEASUREMENT EQUIPMENT		MAJOR MANEFACTURERS											
	Manufacturer / Model	Manufacturer / Model	Manuf.1	Product	Sheet.Type	Manuf.2	Product	Sheet.Type	Manu.3	Product	Sheet.Type	Manuf.4	Product	Sheet.Type
Arizona	Model 920 Field Retroref. Adv. Retro Tech.		3M	Scotchlite	II, IIIA, D, N	Seibulite		II, IIA, III	Fasing		II	Spar-Cal		Vinyl
Arkansas	---		3M	Scotchlite	II, IIIA, D									
California	EC&G Model 550 Photometer/Radiom., Lab		3M		II, IIIA	Seibulite		II, IIA	Reflexite	PC-1000	Vinyl			
Colorado	Advanced Retro Technlogy Inc.		3M		IIIA	Seibulite		IIA						
Connecticut	---		3M			Avery Int.								
Delaware	Gardner Industries, GlossGUard System 85		3M		II, IIIA, D	Avery Int.		II						
Florida	Model 920 Field Retroref. Adv. Retro Tech.		3M		II, IIIA	Seibulite I..		II, IIA	Reflexite		IIIB	Stimsonite		IIIC & IV
Georgia	Portable Retroreflectometer		3M		II, III	Fasing		II						
Idaho	Model 920 Field Retroref. Adv. Retro Tech.		3M	Scotchlite	II, IIIA	Avery Int.	Fasing	II						
Indiana	Model 920 Field Retroref. Adv. Retro Tech.	Model 930B Field Retroref. ART	3M	Scotchlite	II, IIIA	Seibulite	Seibulite	IIA	Reflexite	Reflexite	IIIB			
Kansas	Model 920 Field Retroref. Adv. Retro Tech.		3M	Scotchlite	II, IIIA	Seibulite	Seibulite	II	Fasson	Fasign	II			
Louisiana	Model 920 Field Retroref. Adv. Retro Tech.		3M			Seibulite	(test only)	II						
Maine	---		3M		II									
Michigan	Model 920 Field Retroref. Adv. Retro Tech.		3M		III	Seibulite	(exp.)	IIA						
Minnesota	---		3M		II, IIIA, D	Avery Int.	Fasing	Fluo orang						
Mississippi	Model 920 ART Field Retroreflect., Lab	200,000 Cd Pow. Spot Light (Q-Beam), port	3M		II, IIIA, NR	Avery Int.	Fasing	II						
Missouri	---		3M		II, III									
Montana	Model 920 Field Retroref. Adv. Retro Tech.		3M		II, III	Nippon Carb	Reflexite		Avery Int.		II			
Nebraska	Model 920 Gamma, portable		3M		II, III									
Nevada	Model 920 Field Retroref. Adv. Retro Tech.		3M		II, III									
New Jersey	ESNA (Stimsonite), Lab		3M	Scotchlite	II, IIIA	Avery Int.	Fasing R	II						
New York			3M	Scotchlite	II, III	Avery Int.	Fasing	II	Seibulite	Seibulite	II			
North Carolina	910 F Gamma Scientific Reflectometer		3M		II, IIIA	Fasion	Eng.	II						
Ohio	Model 920 Field Retroref. Adv. Retro Tech.		3M	Scotchlite	II, III	Avery/Den.	Fasing	II						
Oklahoma	Model 920 Field Retroref. Adv. Retro Tech.		3M	Scotchlite	II, III	Nippon Carb	Seibulite	IIA						
Oregon			3M		II, IIIA, D, Vi									
Pennsylvania	Spectra Pritchard (1980), Lab.	EC&G Gamma Scientific, Lab.	3M	Scotchlite	II, III	Seibulite	Seibulite	IIA	Avery Int.	Fasson	II			
	Gamma Scientific Telephot. (IC2000), Lab	ART Model 930/ Gamma Sc.910E (3), field.												
South Carolina	Pritchard, Spectra Photometer 1980A, Lab		3M	Scotchlite	II, IIIA, B	Avery Int.	Fasing	II	Amerace	Stimsonite	IIIB	Reflective	Reflexite	IIIB
Tennessee	Mirolux, portable		3M		II, III									
Texas	Tektronic J16 photometer, lab	Model 920 Field Retroref. Adv. Retro Tech.	3M	Scotchlite	II, III, Vi	Seibulite	Seibulite	II, IIA, III	Kiwalite	Kiwalite	II	Fasing	Fasing	II
Utah	Model 920 Field Retroref. Adv. Retro Tech.		3M		II, III	Fason		II	Seibulite		II			
Vermont	---		3M	Scotchlite	II, III	Seibulite	Seibulite	IIA						
Virginia	Gamma Sc. with Light Tunnel, lab	Model 920 Field Retroref. Adv. Retro Tech.	3M		II, IIIA, D									
West Virginia	Gamma 910 Portable unit	Gamma 920 Portable unit	3M	Scotchlite	II, III	Fasson	1500/900	II, NR						
Wisconsin	Model 920 Field Retroref. Adv. Retro Tech.		3M		HI	Seibulite		II	Avery Int.		II			
Wyoming	Field Retroref. Adv. Retro Technology		3M	Scotchlite	II, III	Mitsubishi	Seibulite	II						

NOTES: II = Engineering Grade (Type II FP-85)
IIA = Super Engineering Grade (type II-a FP-85)
IIIA= High Intensity Grade, encapsulated lenses (type III-A FP-85)
IIIB = High Intensity, Prismatic (type III-B FP-85)
D = High Intensity, Diamond Grade
Vi =Vinyl type sheeting

APPENDIX II

COMPARISON OF STANDARD RETROREFLECTIVITY REQUIREMENTS

STANDARD RETROREFLECTIVITY REQUIREMENTS - COMPARISON

Enginneering Grade - Enclosed Lens (FP-85 II, AASHTO II, ASTM I)

Retroreflectivity Required in cd./foot-cd./sq. yd. (SIA) (Observation Angle/Entrance Agle)

STANDARD	WHITE				RED				ORANGE				BROWN				YELLOW				GREEN				BLUE			
	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30
FP-85	70	30	30	15	14.5	6	7.5	3	25	7	13.5	4	2	1	1	0.5	50	22	25	13	9	3.5	4.5	2.2	4	1.7	2	0.8
AASHTO	70	30	30	15	14.5	6	7.5	3	25	7	13.5	4	1	0.3	0.3	0.2	50	22	25	13	9	3.5	4.5	2.2	4	1.7	2	0.8
ASTM	70	30	30	15	14.5	6	7.5	3	25	7	13.5	4	1	0.3	0.3	0.2	50	22	25	13	9	3.5	4.5	2.2	4	1.7	2	0.8
Arizona	70	30	30	15	14.5	6	7.5	3	25	7	13.5	4	1	0.3	0.3	0.2	50	22	25	13	9	3.5	4.5	2.2	4	1.7	2	0.8
New Jersey (1)	70	30	30	15	14.5	6	7.5	3	25	5	13.5	4	1	0.3	0.35	0.2	50	22	25	13	9	3.5	4.5	2.2	4	1.7	2	0.8
Pennsylvania	90	40	40	20	14.5	6	7.5	3	25	7	13.5	4	2	1	1	0.5	50	22	25	13	9	3.5	4.5	2.2	4	1.7	2	0.8
Texas	85	30	35	15	14.5	6	6	2.5	25	7	12	4	2	1	1	0.5	50	22	25	12	9	4	4.5	2.5	5	2	2	1

Super Enginneering Grade - Enclosed Lens (FP-85 IIA, ASTM II)

Retroreflectivity Required in cd./foot-cd./sq. yd. (SIA) (Observation Angle/Entrance Agle)

STANDARD	WHITE				RED				ORANGE				BROWN				YELLOW				GREEN				BLUE			
	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30
FP-85	140	60	50	28	30	12	10	6	60	22	20	12	5	2	2	1	100	36	33	20	30	10	9	6	10	4	3	2
AASHTO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ASTM	140	60	50	28	30	12	10	6	60	22	20	12	5	2	2	1	100	36	33	20	30	10	9	6	10	4	3	2
Arizona	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
New Jersey	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pennsylvania	140	60	50	28	30	12	10	6	60	22	20	12	--	--	--	--	100	36	33	20	30	10	9	6	10	4	3	2
Texas	140	60	50	28	--	--	--	--	60	20	20	12	--	--	--	--	100	36	33	20	30	10	9	6	--	--	--	--

High Performance - Encpsulated Lens (FP_85 IIIA, AASHTO IIIA, ASTM III)

Retroreflectivity Required in cd./foot-cd./sq. yd. (SIA) (Observation Angle/Entrance Agle)

STANDARD	WHITE				RED				ORANGE				BROWN				YELLOW				GREEN				BLUE			
	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30
FP-85	250	150	95	65	45	25	15	10	100	60	30	25	--	--	--	--	170	100	62	45	45	25	15	10	20	11	7.5	5
AASHTO	250	150	95	65	45	25	15	10	100	60	30	25	--	--	--	--	170	100	62	45	45	25	15	10	20	11	7.5	5
ASTM (2)	250	150	95	65	45	25	15	10	100	60	30	25	--	--	--	--	170	100	62	45	45	25	15	10	20	11	7.5	5
Arizona	250	150	95	65	45	25	15	10	100	60	30	25	12	8.5	5	3.5	170	100	62	45	45	25	15	10	20	11	7.5	5
New Jersey (3)	250	150	95	65	45	25	15	10	100	60	30	25	--	--	--	--	170	100	62	45	45	25	15	10	20	10	7.5	5
Pennsylvania	250	150	95	65	45	25	15	10	100	60	30	25	--	--	--	--	170	100	62	45	45	25	15	10	20	11	7.5	5
Texas	250	150	95	65	40	25	15	10	100	60	30	25	--	--	--	--	170	100	62	45	40	25	15	10	--	--	--	--

High Performance - Prismatic (FP-85, AASHTO III-B, ASTM IV)

Retroreflectivity Required in cd./foot-cd./sq. yd. (SIA) (Observation Angle/Entrance Agle)

STANDARD	WHITE				RED				ORANGE				BROWN				YELLOW				GREEN				BLUE			
	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30	0.2/-4	0.2/+30	0.5/-4	0.5/+30
FP-85	250	95	200	65	45	13.3	28	10	100	26	56	25	--	--	--	--	170	64	136	45	45	11.4	24	10	20	7.6	18	5
AASHTO	250	95	200	65	45	13.3	28	10	100	26	56	25	--	--	--	--	170	64	136	45	45	11.4	24	10	20	7.6	18	5
ASTM (2)	250	80	135	55	35	9	17	6.5	100	34	64	22	--	--	--	--	170	54	100	37	35	9	17	6.5	20	5	10	3.5
Arizona	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
New Jersey	250	95	150	65	45	15	25	10	100	30	60	25	--	--	--	--	170	62	100	45	45	15	25	10	20	7.5	10	5
Pennsylvania	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Texas	250	85	160	55	35	11	22	8	100	34	64	22	--	--	--	--	170	58	110	37	35	11	22	8	--	--	--	--

NOTES:

(1) - also specify entrance angles of 15 and 45 degrees.
(2) - also specify for 0.1 degree observation angle, when required specifically.
(3) - also specify 50 degree entrance angle.
(4) - New Jersey considers also a super high intensity sheeting material (probably Diamond Grade).